Comparative Study of Low-Energy Adaptive Clustering Hierarchy Protocols

Savita Jadhav, Ishwar Panpaliya, and Sangeeta Jadhav

Abstract The wireless sensor networks are composed of miniature power sensors that reach in remote regions. Sensors are alienated into diverse clusters. Among the randomly deployed cluster, one node is elected as cluster head (CH) and all other nodes act as member nodes (MNs) of that cluster. The foremost purpose of cluster head is to aggregate the sensed data from the member nodes to the sink node. Energy expenditure is a vital challenge in WSN as the sensor nodes are equipped with the batteries that are not replaceable. This paper put forward a relative revision of the LEACH protocols for wireless sensor network. The study starts with the review of preceding surveys of LEACH-based protocols. The assessment is carried out on the basis of use of location information, energy efficiency, hop count, base station centralized control, work distributed, self-organization and scalability. Further advantages and disadvantages of these protocols are also mentioned.

Keywords LEACH · EE-LEACH · C-LEACH · WSN

1 Introduction

The wireless sensor network (WSN) is mounting like most impressive and attractive technologies for communicating the information in the current world of Internet of things-based technology. To gather round useful information from the environment, numerous minuscule sensor nodes are arranged in the environment. For sensing and monitoring the factual environment, these sensor nodes are outfitted with signal sensing, processing and trans-receiving units. WSN is swiftly escalated in nearly every field like industries, health care, structural health monitoring, home automation, target tracking, military, agriculture, etc. But the major issue in WSN is the

S. Jadhav (✉) · I. Panpaliya
Electronics and Telecommunication Department, Dr. D. Y. Patil Institute of Technology, Pune, Maharashtra, India

S. Jadhav
IT Department, Army Institute of Technology, Pune, Maharashtra, India

A. Sivasubramanian et al. (eds.), *Futuristic Communication and Network Technologies*, Lecture Notes in Electrical Engineering 792,
https://doi.org/10.1007/978-981-16-4625-6_33

energy scarce of sensors. The nodes perform sensing, processing and trans-receiving of data based on their battery power. These tiny sensor nodes consist of very small size of the battery that provisions fewer sum of energy. Basically, it becomes difficult to transform the drain battery of the sensor nodes from inaccessible environment to get information. The total energy of sensor nodes is dissipated at the time of actual communication; the network lifetime reduces as the sensor nodes become dead. By considering limitations of WSN such as low power, low processing speed, less bandwidth and limited memory capacity, it is essential to utilize this sparse energy reserve competently to enhance the life span of WSN. The large amount of energy is degenerate in small period of time, and the network dies as the data packets are send from the member nodes to the base station (BS). To overcome these predicaments, LEACH routing protocol is a solution in which based on the probability theory every node can become cluster head (CH) and member node transmits there data in each iteration. The selection of cluster head randomly makes LEACH energy economy protocol. The probability approach is used in design of LEACH protocol to select any node as a cluster head. This procedure takes place in random manner. The tasks performed by member node are sensing the data from environment and sending this data to cluster head. The CH performs some advanced tasks like data reception from all member nodes which is the most energy-consuming processes, aggregating data and transmitting it to the sink node. Hence, cluster head guzzles huge quantity of energy compared to all other member nodes. After completion of iteration, one of the member nodes becomes cluster head and processes continue till all nodes in network become cluster head. By using this approach, none of sensor node gets energy discharge rapidly and there is impartial and consistent power eating in the sensor network; this step directs to improvement in lifetime of network. Several surveys [1–6] are scrutinized based on diverse approaches like node mobility, routing protocols, node localization techniques, optimization strategies and intelligent schemes. This comparative study proposed structured and inclusive review of the literature containing enrichment in LEACH clustering and routing protocols. The innovative categorization is based on diverse parameters like distance between nodes, selection of route, network connectivity and coverage. In [1], authors present a survey consisting of advancements in LEACH routing protocol. The taxonomy of protocols is based on data communication. Sixty LEACH alternatives are offered in this review with merits and demerits of each protocol. Also, nine diverse techniques are used for comparison of parameters. For classification of protocols, two different approaches are used as single-hop and multi-hop communication. In [2], authors presented an outline of advancements in LEACH. The comparison of protocols is based on node arrangement knowledge, node mobility and data communication process. The limitation of this survey is that it does not present any categorization. In [3], authors pay attention on the improvements in the LEACH-based clustering protocol. This survey presents six different types of LEACH protocol which is lacking in classification technique. The paper [4] surveyed twenty-one routing protocols based on LEACH. This paper also mentioned qualitative comparison with other existing surveys. The paper ends up with future guidelines. In [5], authors presented improvement over conventional LEACH. The limitation of [5] is only five protocols are used for survey without any classification

Table 1 Comparison of preceding reviews based on LEACH protocols

Ref	Key idea	Limitations
[1]	To discuss and compare several LEACH protocols with different performance parameters	Classification is based on two communication categories as single hop and multi-hop
[2]	To describe various LEACH variants	Three parameters compare the performance exclusive of further classification
[3]	To conquer uneven cluster head allotment in LEACH	This paper discusses merely six LEACH versions, not mentioned classification technique
[4]	Twenty-one types of improvements in LEACH are surveyed. Qualitative comparison with other existing surveys	Six types of parameters are used for giving comparison of different protocols in this survey. For selection of CH's selection and cluster formation, future guidelines are given
[5]	Improvement over conventional LEACH is presented	Only five protocols are used for survey without any classification and parameter comparison
[6]	Pros and cons of LEACH along with its descendants are discussed	Ten protocols are discussed without any comparison and classification

and parameter comparison. Table 1 indicates comparison of most accessible surveys available for reference.

The organization of this survey follows the following sequence: The overview of fundamental LEACH protocol architecture in detail with two phases is presented in Sect. 2; the comprehensive study of advancements taken place in basic LEACH protocol is conferred in Sect. 3; relative analyses of LEACH have been presented in Sect. 4; at the end, Sect. 5 concludes the paper.

2 LEACH: Protocol Architecture

This is a state-of-the-art protocol working on random revolution of cluster heads for uniformly distributing energy between cluster members and entire sensor network. The main working of LEACH [7] consists of the following two vital suppositions:

1. The base station situated at fixed position distant from the sensing devices,
2. The network type is homogeneous.

The cluster configuration and to employ cluster heads as routers for communication is the major initiative of LEACH. The construction of clusters is based on localized coordination. The pattern of clusters manages data transmitted to sink, reduces data congestion on communication link and creates network more scalable and robust. Figure 1 illustrates cluster arrangement and routing in LEACH protocol.

(i) Setup stage: A random number is generated by each node among 0 to 1 after that selected number is judged against $T(n)$, the threshold value. If chosen numeral is

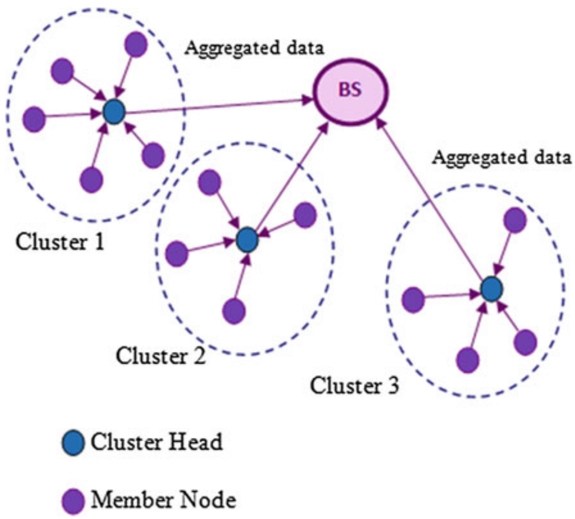

Fig. 1 LEACH cluster configuration and routing

fewer than T (n), that node acts as a cluster head. Equation (1) expresses the threshold $T(n)$.

$$T(n) = \frac{P}{1 - P \times \left(r \bmod \frac{1}{P}\right)} \quad \text{and}\ T(n) = 0 \quad \text{if}\ n \neq G \tag{1}$$

where n indicates the node identification, p shows the cluster head prospect, r gives the recent encircling number and G indicates non-cluster head nodes in the first $1/P$ rounds. Following to $1/P$ rounds, all nodes will act as cluster head using this threshold value with probability P. The node which becomes cluster head in this round will not be cluster head in next $1/P$ rounds. In this way, the number of nodes which are capable to become cluster head goes on reducing and the probability of becoming cluster head among the remaining member nodes increases.

(ii) Steady-state stage: The key function of this stage is data processing, compressing and transmitting to the sink node. This data transmission is in frame format with combination of multiple frames. The structure is revealed in Fig. 2.

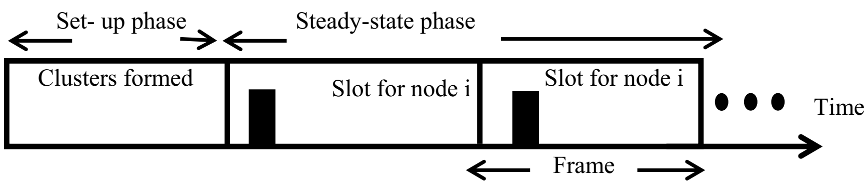

Fig. 2 LEACH protocol process

3 Advancements in Low-Energy Adaptive Clustering Hierarchy (LEACH)

3.1 Advanced LEACH (A-LEACH) (2008)

Ali et al. [8] present advanced low-energy adaptive clustering hierarchy (A-LEACH). In this procedure, nodes take independent assessment with no central involvement. In A-LEACH best cluster head selection, rotating cluster head position, adaptive clustering are the important processes takes place which gives even allocation of energy among all nodes of the network. Similar to LEACH, the A-LEACH works on two phases. In setup phase cluster formation and in steady-state phase data broadcasting to sink node. The formula for threshold is given in Eqs. (2) and (3). The advantages of A-LEACH are it increases network lifetime and energy efficiency and reduces communication distance with the sink node and cluster formation takes place without node position information.

$$T(n) = G_p + CS_p \tag{2}$$

Here,

$$G_p = \frac{K}{N - k(r \mod N/k)} \tag{3}$$

3.2 LEACH-B (Balanced) (2010)

Tong and Tang [9] present a LEACH-balanced (LEACH-B) protocol. The operation is divided in two rounds. Cluster formation and cluster head selection in first round are followed by steady-state phase in which nodes' residual energy is measured for cluster head node selection. The main theme of this protocol is that it has balanced and uniform cluster formation to save the energy consumption. LEACH-B has improved energy efficiency and longer network lifetime than LEACH.

3.3 Centralized LEACH (LEACH-C) (2013)

Tripathi et al. [10] propose LEACH-C which is advancement over basic LEACH protocol. For cluster formation, node's leftover energy and distance of all the member nodes to cluster head are considered. The cluster formation is centrally coordinated by the sink node. In the first round, all nodes of cluster drive their location information and energy level to sink node. The sink node using Eq. (4) estimates the average energy of the network. The higher energy nodes are marked eligible for becoming cluster head. The selected cluster head (CH) and member nodes are broadcasted to the network by base station. Next matching of node's own ID with cluster head ID takes place. If it matches, it acts as cluster head or else to transmit data to cluster head it will find TDMA slot. The LEACH-C has same data transmission phase as LEACH. The advantage of LEACH-C is that as cluster head node is positioned at the center of cluster energy expenditure is uniform, and the network lifetime is improved. But a GPS receiver is placed on every node which increases energy cost and LEACH-C is not compatible for large area of network is the limitations.

$$T(n)_{\text{new}} = \frac{P}{1 - P \times (r \mod \frac{1}{p})} * E_{n\_\text{current}}/E_{n\_\max} \tag{4}$$

where

E_{n_current} is the present sum energy and $E_{n\_\max}$ is the preliminary quantity of energy.

3.4 E-LEACH (2014)

Patel and Jinwala [11] propose E-LEACH (end-to-end secure LEACH) as an improvement of LEACH. E-LEACH applies homomorphic encryption for safe data processing in WSN. By using algebraic characteristics in homomorphic encryption, data processed algebraically devoid of decryption. This results in less energy with data privacy. It works on three types of keys. The first is a pairwise shared key. This key is to guarantee integrity and authentication at the time of communication. The second key is session key which works for each sitting of CH. Last is group key to authenticate nodes for CH. To achieve homomorphic encryption, it uses Paillier encryption scheme.

3.5 Fuzzy LEACH (F-LEACH) (2017)

Balakrishnan et al. [12] present fuzzy logic-based energy-efficient clustering hierarchy (F-LEACH) for non-uniform WSN. For increasing the network lifetime and selecting optimal cluster head node, F-LEACH uses residual energy, centralized nodes and distance between nodes. Again for appropriate cluster head selection, the probabilistic and weight-based techniques are combined together. The performance of F-LEACH may be increased in the future by introducing coverage redundancy and number of hop counts.

3.6 LEACH-PSO (2013)

Natarajan et al. [13] propose LEACH-PSO based on swarm particle algorithm. In particle swarm optimization (PSO) approach, objective function is formulated based on the outstanding energy, distance of member node to cluster head and node density. The combination of LEACH and PSO results in optimized cluster head selection, reduction in distance between cluster head and member node and uniform energy distribution in entire network. By using this approach, network can balance load among all the nodes and improves network life span. Where nodes distributed unevenly in WSN, LEACH-PSO is not suitable there. In addition to this, every isolated node should join the nearest cluster. More energy can be consumed while transferring information from the cluster head node to sink node.

3.7 LEACH-K (2014)

Nigam and Dabas [14] propose LEACH-K which makes changes in LEACH protocol by using K-means algorithm. In LEACH for selecting cluster head, residual energy of particular node is not considered and routing is of single-hop type. LEACH-K takes these two issues for further improvement. The equation for calculating threshold value is given by (5). As the selection of cluster head has the major impact on the advancement process of LEACH, the cluster head number K must be considered to improve result. The limitation of LEACH-K is that more isolation in nodes reduces node utilization, and increased energy consumption as LEACH-K is not responsive in remote nodes.

$$
\begin{aligned}
T(n) &= \frac{P}{1 - P \times (r \mod \frac{1}{P})} * E_{n\_\text{current}}/E_{n\_\max} \times K_{\text{optimals}} \quad \text{if} \quad n \notin G \\
T(n) &= 0 \quad \text{Otherwise}
\end{aligned} \tag{5}
$$

3.8 LEACH-R (2012)

Wang and Zhu [15] present the cluster head selection stage which is improved in LEACH-R. In comparison with LEACH, cluster head and relay node selection are improved in LEACH-R. Residual energy is used in threshold calculation according to which small energy nodes do not act as cluster head. Again selection of relay node is based on lingering energy and distance to base station. The relay nodes are placed for communication in between cluster head to base station and cluster head to another cluster head in network. LEACH-R algorithm works on setup phase and steady-state phase. In comparison with LEACH, the LEACH-R saves almost 20% energy. Incomplete information transmission is the limitation of LEACH-R.

3.9 TL-LEACH (Two-Level Hierarchy) (2005)

Loscri et al. [16] propose multi-level communication. A new level of hierarchy is used in TL-LEACH for information transmission in between cluster head and base station. This technique increases number of cluster heads and decreases distance of data transmission to base station which results in decrement in node density for data transmission. The hierarchical network design is based on two levels as primary level in which cluster head is situated in the hierarchy at the topmost position after base station denoted as CHi and secondary level is a lower level denoted as CHij. Some end nodes are positioned at the end of hierarchy. At the second level, TL-LEACH initiates fractional limited working out in each cluster head. The top level performs the local computation for data transmission to base station. This technique shares the energy consumption equally among all the sensors of large density networks. TL-LEACH uses node localization to facilitate scalability and robustness.

3.10 Cluster Head LEACH (CH-LEACH) (2017)

Abushiba et al. [17] proposed cluster head selection (CH-LEACH) build on cluster count in the network gird area. To check the network coverage, the maximum number of the cluster head is elected in diverse situation. CH-LEACH selects cluster heads randomly, and in every round, each cluster head is assigned to nearest central location. The CH-LEACH minimizes energy consumption. The network lifetime is improved 91% than LEACH.

3.11 Multi-hop LEACH (MH-LEACH) (2007)

Xiangning and Yulin [18] presented MH-LEACH protocol in which every cluster head directly communicates with base station without considering distance between them. This consumes a lot of energy if distance is large. This drawback of LEACH is overcome in multi-hop LEACH (MH-LEACH). The MH-LEACH presents best possible pathway. It takes multiple hops from cluster head to base station. It performs first multi-hop communication between different cluster heads and second in between cluster heads to base station. In second stage, it uses optimal path for information transfer from cluster head to base station. The remaining things are same as the state-of-the-art LEACH protocol. In MH-LEACH, communication changes from single hop to multi-hop which results in improved energy consumption.

3.12 Enhanced Energy-Efficient LEACH (EEE-LEACH) (2015)

Bharti et al. [19] present an enhanced energy-efficient LEACH (EEE-LEACH) routing algorithm. In EEE-LEACH, member node uses shortest path for information transmission to cluster head via multi-hop communication technique. For improvement in basic LEACH routing protocol, EEE-LEACH uses another technique that is formation of master node for information transmission. The master head node takes the information from cluster head. Here, both master head and cooperative master head use cooperative MIMO approach to transmit the processed data to base station which is located far away in the network. For selection of cluster head, cooperative master head node and master head neighborhood distance among sensor nodes and residual energy of the nodes are considered.

3.13 Improved LEACH (I-LEACH) (2014)

Kehar and Singh [20] propose an integrated approach in which cluster head selection is based on three-level decision tree. The first important parameter of decision tree is residual energy. For balancing the clusters, protection scheme is planned in I-LEACH. Last option is the position of the base station which is placed in the network such that it covers high density of nodes. The cluster head selection depends on residual energy and distance between adjacent cluster head nodes. Routing technique is of reactive type. Nodes will send information as on if sensed information is above threshold value.

3.14 ETL-LEACH (Enhanced Two-Level Hierarchy) (2019)

Manzoor et al. [21] present ETL-LEACH which is advancement over the TL-LEACH. The TL-LEACH has two major limitations as it is not compatible for large-scale networks and node communication. The main task of ETL-LEACH is to decrease energy utilization. Similar to TL-LEACH, secondary cluster head nodes are treated as relay nodes which are placed between the primary cluster heads and the end nodes. ETL-LEACH prepares an energy table at the primary and the secondary cluster head nodes for cluster formation. This table gives the information of residual energy of end nodes to secondary cluster head nodes. This process is useful in switching the role of cluster head. The advantage of ETL-LEACH is that it is applicable to large-scale network. Use of mobile sink will be future advancement in ETL-LEACH with added mobility.

3.15 LEACH-T (2016)

Al Sibahee et al. [22] propose three layers (LEACH-T). The function of layer formation is to decrease distance between cluster head and base station. A separate cluster head is allotted to each layer. The LEACH-T operation is divided into three layers. The function of first layer is to collect the data from all member nodes of cluster. To collect the data from cluster head is the function of second layer. At last, the third layer functions if there is large distance between the second-layer cluster head and sink nodes. LEACH-T minimizes power consumption and solves the distance problem between cluster head and sink nodes.

4 Comparative Analysis

The comparison is carried out on the basis of use of location information, energy efficiency, hop count, base station centralized control, work distributed, self-organization and scalability as shown in Table 2. Advantages and disadvantages of recent clustering-based protocols are presented in Table 3. The conclusions are drawn on the basis of this review, and comparison tables are summed up below.

1. In WSN, sensor nodes are energy constrained, so vital design criteria for the majority of the LEACH protocols are to reduce energy consumption.
2. In WSN, enhanced security can be attained but it results in high energy consumption which increases cost. By applying innovative cryptographic techniques, researchers can accomplish improved protection through least energy consumption.
3. In large-scale wireless sensor networks, LEACH experiences communication problems as cluster heads directly communicate to the sink node. This reduces network lifetime. To solve this problem, researchers can use multi-hop protocols as they are accomplished with the optimal and shortest path techniques.
4. The optimization techniques are helpful in configuring best possible numbers of clusters and to decide most favorable numbers of cluster heads. Optimization can also utilize for most favorable deployment of nodes in network.
5. In WSN, one of the most talented research areas is energy harvesting. Harvesting techniques can be properly utilized in WSN as it increases hardware cost. The cosmological power, storm energy, kinetic energy and wireless charging are the diverse sources for energy harvesting.
6. In WSN, mobility is a popular research area. In comparison with static sensor networks, mobility of sensor nodes is flexible, and mobile nodes can be positioned in any scenario and supervised with quick topology transform. This area is less explored in modifications of LEACH. Researchers can recommend novel mobility patterns for cluster heads and sink nodes.

Table 2 Comparison of recent clustering-based protocols

Routing protocol	Location information	Energy efficiency	Hop count	Centralized control	Work distributed	Self-organization	Scalability	Improvements over LEACH
A-LEACH	Yes	Very high	Single hop	No	Yes	Yes	Good	All nodes are distributed in clusters. Member nodes send data directly to sink in LEACH
LEACH-B	No	High	Single hop	No	Yes	Yes	Good	The communication restricted between non-cluster head nodes. Distance between all nodes is known in LEACH
LEACH-C	Yes	High	Single hop	Yes	No	Yes	Good	Selection of cluster heads is done by base station. In LEACH, all nodes in cluster decide cluster head
E-LEACH	Yes	Very high	Single hop	No	No	Yes	Good	Predetermined number of clusters in E-LEACH
LEACH-F	Yes	Very high	Single hop	Yes	No	No	Limited	Fixed number of clusters and number of nodes in network
I-LEACH	Yes	Very high	Single hop	No	Yes	Yes	Very good	Twin node detection and assignment of sub-CH (SCH) nodes

(continued)

Table 2 (continued)

Routing protocol	Location information	Energy efficiency	Hop count	Centralized control	Work distributed	Self-organization	Scalability	Improvements over LEACH
K-LEACH	Yes	High	Single hop	No	No	No	Limited	Cluster formation is based on K-mediod technique
M-LEACH	Yes	Very high	Multi-hop	No	No	Yes	Very good	Multi-hop between CH and BS
T-LEACH	Yes	Very high	Single hop	No	Yes	Yes	Good	Role of cluster head nodes continues in next round if that node has more energy than threshold value
TL-LEACH	Yes	Very high	Multi-hop	No	Yes	Yes	Very good	Use of multi-hop communication

Table 3 Advantage and disadvantages of recent clustering-based protocols

Algorithm	Advantages	Disadvantages	Technique used
LEACH	Direct communication between cluster head and base station. The first state-of-the-art clustering protocol	More power consumption, addition or removal of dead nodes is not possible	Based on two phases, setup phase and steady-state phase
LEACH-C	Improvement in performance	Mobile nodes give poor performance, not suitable for large-scale networks; GPS installed on every node increases overhead	For cluster formation, apply a central control algorithm
A-LEACH	Increases network lifetime and throughput. Decreases node failure	Increased energy consumption, not appropriate for large-scale networks	Use of distributed algorithm for cluster selection. Cluster head mobility reduces distance; the member nodes need to transmit data
Multi-hop LEACH	For large size networks consumes less energy	Hotspot created at sink as multiple cluster heads transmit data to sink simultaneously	Implement multi-hop communication among cluster heads and sink and select optimal path for data routing
E-LEACH	Network lifetime improved	Constant round time consumes more energy	Leftover energy of nodes is used for cluster head selection
LEACH-R	Inter-cluster multi-hop routing improves network performance	Only suitable for small-scale networks	To enhance cluster structure uses node localization and node density
TL-LEACH	Power consumption reduction	End-to-end delay increases	Employ two-level transmission approaches

7. In WSN, network coverage is one of the important research areas which is not extended in depth in LEACH advancements, hence requiring more attention in this field.
8. The optimization techniques need to be developed for node localization as major LEACH variants use GPS for getting location coordinates of randomly deployed sensor nodes which results in increased cost and energy consumption.
9. In large area, WSN fault tolerance put forth a main impact on the network lifetime. Hence, resourceful algorithms must be designed that deal with faults.
10. In WSNs, network complexity is a vital factor in protocol design, as it affects overall network performance. Hence, low-complexity LEACH-based protocol design is essential.

11. Congestion control is one of the important areas of WSN, as it affects quality of service parameters like packet delivery rate, latency and energy consumption. Due to this, additional research attention is required for design of congestion-aware clustering and routing protocols.

5 Conclusion

The paper presents inclusive review of LEACH and its variants. This paper discusses and compares 15 improvements in LEACH. Localization, hop count, overheads, scalability and energy efficiency are the performance comparison parameters in this paper. Most of the discussed protocols are of distributed type and use node localization techniques. Using GPS for getting position coordinates is costly. Only few protocols have considered the energy expenditure factor in cluster head selection process and in cluster formation. Many other parameters such as node position, hop count, number of nodes, neighboring distance and mobility pattern are concentrated by researchers other than energy consumption which is essential factor of network design. Some future research points are highlighted in this paper which can be considered in designing improved and advanced versions of LEACH-based protocol. In multimedia and real-time WSN applications, LEACH-based clustering and routing techniques should be addressed profoundly.

References

1. Singh S, Kumar P, Singh J (2017) A survey on successors of LEACH protocol. IEEE Access 5:4298–4328
2. Maurya P, Kaur A (2016) A survey on descendants of LEACH protocol. Int J Inf Eng Electron Bus 8:46–58
3. Arora V, Sharma V, Sachdeva MA (2016) Survey on LEACH and other's routing protocols in wireless sensor network. Int J Light Electron Opt 127:6590–6600
4. Al-Shalabi M, Anbar M, Wan T-C, Khasawneh A (2018) Variants of the low-energy adaptive clustering hierarchy protocol: survey, issues and challenges. Electronics 7:136
5. Vyas IA, Panchal KJ (2017) A survey on LEACH protocol and its successors. Int J Adv Res Innov Ideas Educ 3(6)
6. Hitesh M, Shivarkar SA, Muzumdar AA, A survey on LEACH in WSN. https://www.researchgate.net/publication/315728088
7. Heinzelman WB, Chandrakasan AP, Balakrishnan H, An application-specific protocol architecture for wireless microsensor networks. IEEE Trans Wirel Commun 1(4):660–670
8. Ali MS, Dey T, Biswas R (2008) ALEACH: advanced LEACH routing protocol for wireless microsensor networks. In: Proceedings of international conference electrical computer engineering, pp 909–914
9. Tong M, Tang M (2010) LEACH-B: an improved LEACH protocol for wireless sensor network. In: 6th international conference on wireless communications networking and mobile computing (WiCOM), Chengdu, pp 1–4
10. Tripathi M, Gaur MS, Laxmi V, Battula RB (2013) Energy efficient leach-C protocol for wireless sensor network. In: Third international conference on computational intelligence and information technology (CIIT 2013). IET, pp 402–405

11. Patel HB, Jinwala DC (2014) E-LEACH: Improving the LEACH protocol for privacy preservation in secure data aggregation in wireless sensor networks. In: 2014 9th international conference on industrial and information systems (ICIIS). Gwalior, pp 1–5
12. Balakrishnan B, Balachandran S (2017) FLECH: fuzzy logic based energy efficient clustering hierarchy for nonuniform wireless sensor networks. Hindawi, Wirel Commun Mobile Comput 2017, Article ID 1214720
13. Natarajan M, Arthi R, Murugan K (2013) Energy aware optimal cluster head selection in wireless sensor networks. In: 2013 fourth international conference on computing, communications and networking technologies (ICCCNT), Tiruchengode, pp 1–4
14. Nigam GK, Dabas C (2018) ESO-LEACH: PSO based energy efficient clustering in LEACH. J King Saud Univ Comput Inform Sci
15. Wang N, Zhu H, An energy efficient algorithm based on LEACH protocol. In: 2012 international conference on computer science and electronics engineering
16. Loscri V, Morabito G, Marano S (2005) A two-levels hierarchy for lowenergy adaptive clustering hierarchy (TL-LEACH). In: Proceedings IEEE vehicle technology conference, vol. 62(3), 1809–1813
17. Abushiba W, Johnson P, Alharthi S, Wright C (2017) An energy efficient and adaptive clustering for wireless sensor network (CH-leach) using leach protocol. In: 2017 13th international computer engineering conference (ICENCO) Cairo, 50–54
18. Xiangning F, Yulin S (2007) Improvement on LEACH protocol of wireless sensor network. In: Proceedings of international conference sensor technology applied, pp 260–264
19. Bharti A, Devi C, Bhatia V (2015) Enhanced energy efficient LEACH (EEE-LEACH) algorithm using MIMO for wireless sensor network. In: 2015 IEEE international conference on computational intelligence and computing research (ICCIC), Madurai, pp 1–4
20. Kehar V, Singh R (2014) Evaluating the performance of reactive I-LEACH. In: 2014 international conference on advances in computing, communications and informatics (ICACCI), New Delhi, pp 2105–2109
21. Manzoor K, Jokhio SH, Khanzada TJS, Jokhio IA (2019) Enhanced TL-LEACH routing protocol for large-scale WSN applications. 2019 cybersecurity and cyber forensics conference (CCC) Melbourne, Australia, 35–39
22. Al Sibahee MA, Lu S et al (2016) LEACH-T: LEACH clustering protocol based on three layers. In: 2016 international conference on network and information systems for computers (ICNISC), Wuhan, pp 36–40